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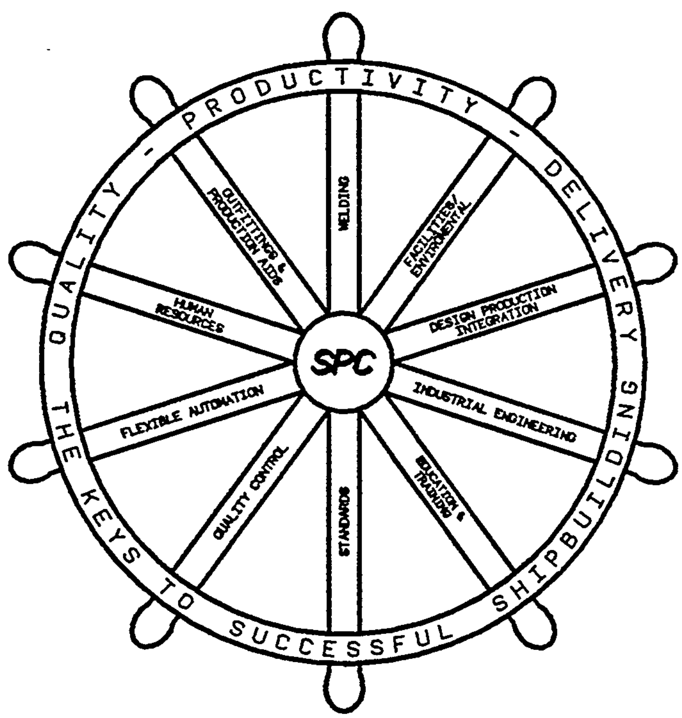

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Implementation of HSLA-100 Steel in Aircraft Carrier Construction - CVN 74

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ABSTRACT

High Strength Low Alloy (HSLA)-lW steel was developed to be less sensitive to hydrogen embrittlement than High Yield (HY)-1OO steel. The primary benefits sought through the use of this new steel were savings in energy, labor, and scheduling that would result from reduced preheat for welding.

This paper reviews the overall efforts required to implement the use of HSLA-1OO steel during CVN 74 aircraft carrier construction. It discusses the engineering and design effort required to incorporate a new material on a vessel midway through construction. Also included is a discussion of the development of an implementation plan which ensures successful welding procedure qualification, production welding, and inspection of HSLA-1OO welds.

Results confirm that HSLA-1OO steel can be successfully substituted for HY-1OO steel in a shipyard environment and significant benefits can be realized from reduced welding preheat. Also, key elements of future applications of HSLA-1OO are presented.

NOMENCLATURE

CVN	(Aircraft) Carrier Vessel Nuclear
CVN 73	*USS George Washington*
CVN 74	*USS John C. Stennis*
CVN 75	*USS United States*
CVN 76	Proposed New Aircraft Carrier
NAVSEA	Naval Sea Systems Command
HY	High Yield Strength Steel
HSLA	High Strength Low Alloy Steel
SAW	Submerged Arc Welding
GMAW	Gas Metal Arc (MIG) Welding-Spray Transfer
GMAW-P	Gas Metal Arc Welding-Pulsed Transfer
SMAW	Shielded Metal Arc (Stick) Welding
MT	Magnetic Particle Inspection
VT	Visual Inspection
HSS	High Strength Steel (351.7 MPa, 51 KSI Yield Strength)
0ss	Ordinary Strength Steel (234.5 MPa, 34 KSI Yield Strength)
FCAW	Flux Cored Arc Welding

INTRODUCTION

In 1985 the U.S. Navy initiated a program to develop a High Strength Low Alloy (HSLA-1OO) steel to replace High Yield (HY-1OO) steel for ship construction. The program was based on the successful development of HSLA-80 steel as a substitute for HY-80 steel which resulted in cost savings due to reduced preheat requirements for welding. The goal of the program was to develop a steel which met or exceeded the strength and toughness of HY-1OO steel (l). This new steel would be welded using the same consumables and processes as used in the welding of HY-1OO, but with reduced 15.6°C (60’F) preheat. This is much lower than the required minimum preheat for welding HY-1OO, which varies from 51.7ºC (125°F) to 93.3°C (200°F), depending on thickness and the welding process used.

In 1987, Naval Sea Systems Command (NAVSEA) tasked Newport News Shipbuilding to evaluate the weldability of HSLA-1OO steel under various preheat conditions. The results of the weldability evaluation demonstrated that HSLA-1OO steels could be welded together at up to 25.4 mm (1.0 in.) thickness at 15.6°C (60°F) minimum preheat, with the same processes and consumables being used for HY-1OO steels (2). It should be noted that the aircraft carrier design criterion allows the use of undermatched strength consumables (MIL-1OOS and MIL-l 1018) for welding 689.7 MPa (100 KSI) yield steel. The cost of HSLA-1OO steel at the time of the study was slightly more than HY-1OO steel. Therefore, the major cost savings resulted from reduced preheat requirements for

welding. It was determined that about half of the approximate 19,800 metric tons (18,000 long tons) of HY-1OO steel on an aircraft carrier is 25.4 mm (1.0 in.) and less in thickness.

In March of 1989 NAVSEA completed their testing and evaluation phase. At this time a letter of certification was provided indicating that HSLA-1OO was a qualified substitute for HY-1OO steel in CVN construction and could be directly substituted with the following limitations

1. Hull structural plating applications up to and including 102 mm (4 in.) thick were allowed,

2. All crack arrest structure was prohibited from substitution, and

3. All NAVSEA (Nuclear) Code 08 structure was prohibited from substitution.

IMPLEMENTATION

In November 1989, a contract modification for CVN's 74 and 75 was authorized by NAVSEA. This modification allowed the direct substitution of HSLA-100 for HY-1OO to the maximum extent practical within the guidelines previously discussed. The experience base for welding HSLA-1OO steel was too limited to allow the wholesale substitution for all HY-1OO steel in the unrestricted areas of the carriers. Therefore, an implementation plan for its incorporation had to be submitted and approved by NAVSEA. This plan was intended to address welding procedure qualification and create a system to track weld defect rates for HSLA-100 welding as compared to similar HY-1OO welds. Also, the plan required an appropriate corrective action agenda based on quality trends observed during welding.

Plan Development And Approval

When the contract change for HSLA-1OO substitution was authorized, CVN 74 construction was already well under way. Any significant increase in rework and overall cost, or delays to the construction schedule could not be tolerated therefore, close scrutiny of details, and a prudent approach were necessary. The overall construction scheme was already laid out. Most of the drawings were nearly complete, and a large quantity of steel had already been ordered. Many of the lower hull units were fabricated, welded and ready to be erected. However, a limited window of opportunity did exist that would allow a significant substitution of HSLA-1OO in areas where HY-1OO had not yet been ordered, or where purchase orders could still be modified.

The implementation plan was approved by NAVSEA in July 1990. The plan contained the following key elements:

1. Tonnage, thickness, and location of HSLA-1OO steel ordered for the implementation phase;

2. Welding procedure and welder performance qualification details;

3. Nondestructive test criteria for the initial phase of work

4. A system for tracking HSLA-1OO weld defect rates compared to HY-1OO welding; and

5. A corrective action agenda in the event higher defect rates occurred.

The initial application material thickness had to be 25.4 mm (1.0 in.) thick or less.

Approximately 770 metric tons (700 long tons) of HSLA-1OO steel plate were earmarked for the initial hull structural application. About 440 metric tons(400 long tons) of this material was 25.4 mm (1.0 in.) thick, and the remainder was 22.2 mm (0.875 in.) thick.

Upon. successful completion of the implementation effort, welding of HSLA-1OO steel greater than 25.4 mm (1.0 in.) in thickness with reduced preheat would be permitted, providing that supporting welding procedure qualification data could be developed.

Welding Procedure Qualification

The criteria for new construction CVN weld`ing procedure and welder performance qualification is found in MIL-STD-248C (3). Since HSLA-1OO steel was not addressed in this document, supplemental qualification provisions were developed and addressed in the implementation plan for HSLA-1OO steel.

Qualification test requirements were patterned after those for HY-1OO, since the same welding

consumables are used. There were, however, two key elements that dlffered Procedure qualification tests had to be conducted on weldments produced with the reduced preheat temperature intended for the procedure. In addition, welding procedure maximum material thickness was limited to that used for the actual test weldment, when reduced preheat was included in the procedure.

There were four categories of welding procedure qualification tests detailed in the plan:

1. Prior tests conducted on HSLA-1OO with reduced preheat developed under the certification program;

2. Prior qualified HSLA-80, HY-80 and HY-1OO teats that Supported high use (152 meters [500 feet] or more of weld length) service provenprocedures (normally coupled with one or more similarly produced, reduced preheat HSLA-1OO test);

3. Prior qualified tests (including those of dissimilar materials) that support limited use (less than 152 meters [500 feet] of weld length) service proven procedures; and

4. Additional planned procedure qualification work.

In all cases, any deviation from the types of tests required in MIL-STD-248C for HY-1OO welding was required to be identified in the request for NAVSEA approval along with technical rationale to permit the deviation.

Personnel who were qualified to weld HY-1OO, were also considered qualified to weld HSLA-1OO when using the same process and filler material.

Trades Review

Once procedure qualification reports were approved, anew welding procedure was developed and issued for structural trades use. Other quality control procedures were also revised to accommodate working with HSLA-1OO steel.

Prior to the start of production fitting and welding, key personnel from all primary structural trades and support departments participated in a review of the implementation plan. This included a review of significant changes to any procedure requirements, as well as a review of the approach to be used for documentation and collection of information during the first use of each welding process. In the event that any significant unexpected problems occurred, the shipyard was prepared to address them quickly and thoroughly.

Corrective Action Agenda

During the first weeks of production welding, increased surveillance was performed by quality assurance and welding engineering personnel. The shipyard was prepared to reevaluate the use of reduced preheat at the first sign of any negative quality trend. The contingency plan was to use normal HY-1OO welding requirements until a specific cause, and necessary corrective action could be determined.

Application Of Welding Process

Shop construction began in March 1991 with main deck panels being welded together using butt joints (Figure 1). The typical joint design for these welds is shown in Figure 2. The temperature in the

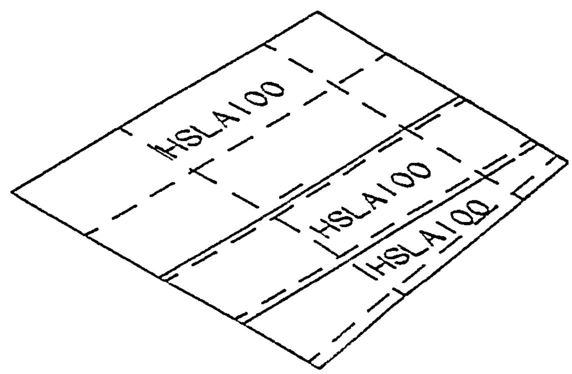

Figure 1 Example of an HSLA-1OO deck panel. Dashed lines indicate backup structure locations

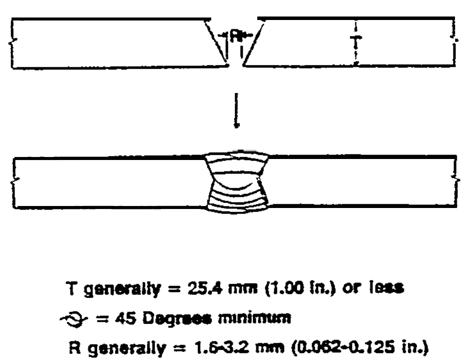

Figure 2 Typical joint design for HSLA-1OO butt welds using SAW

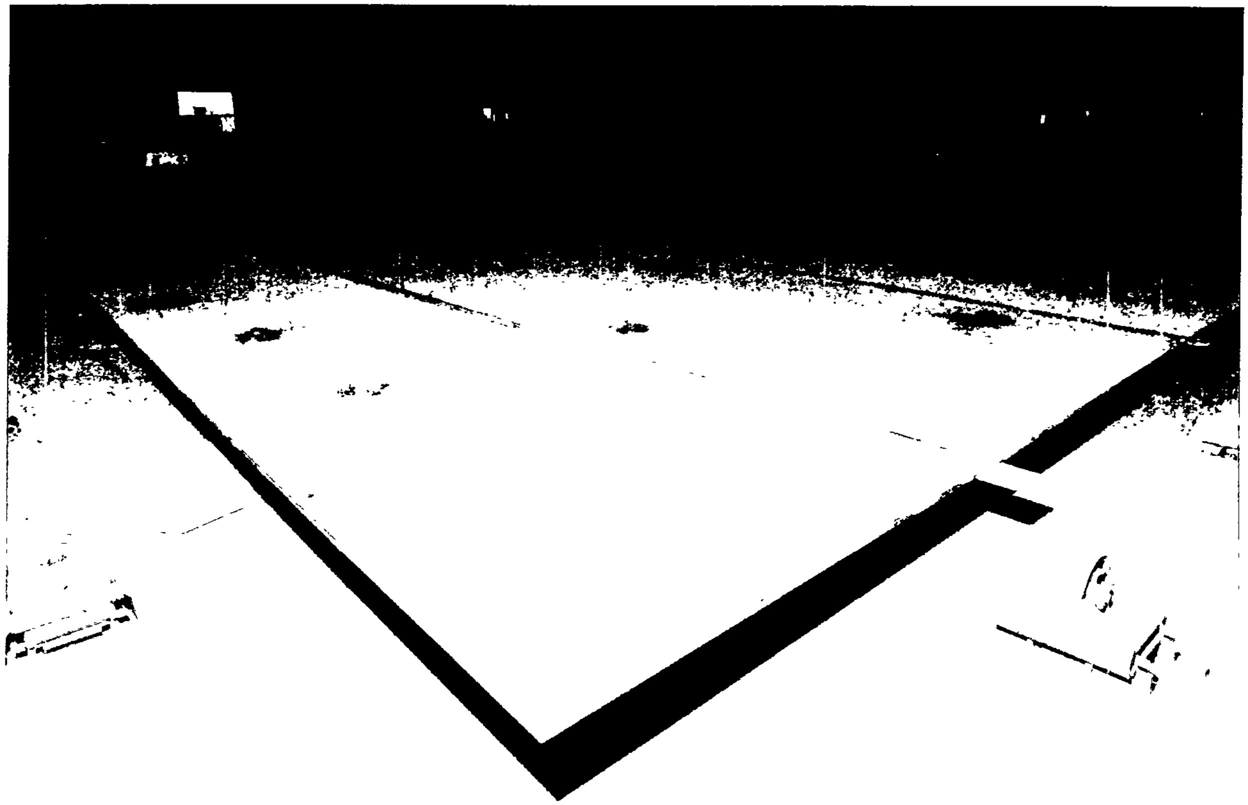

Figure 3 CVN 74 HSLA-100 deck panel after submerged arc welding

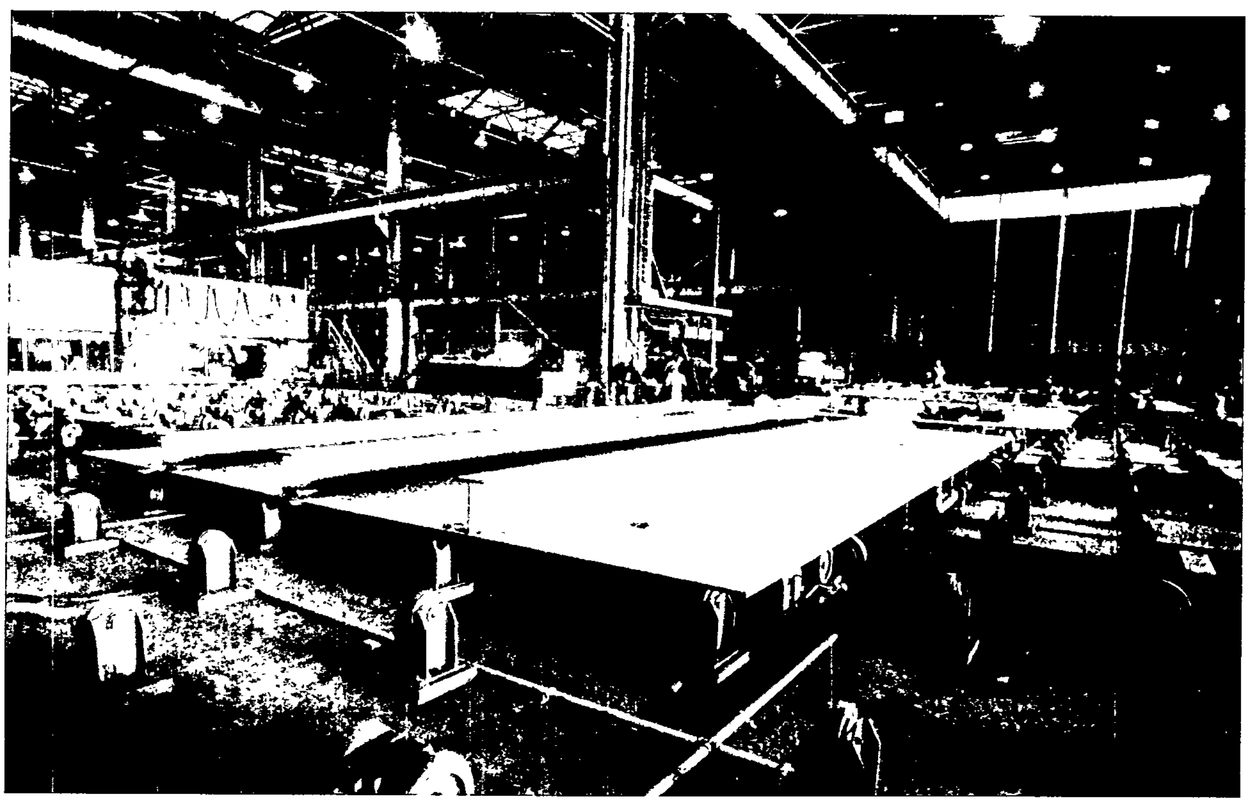

Figure 4 CVN 74 HSLA-100 deck panel with stiffeners attached

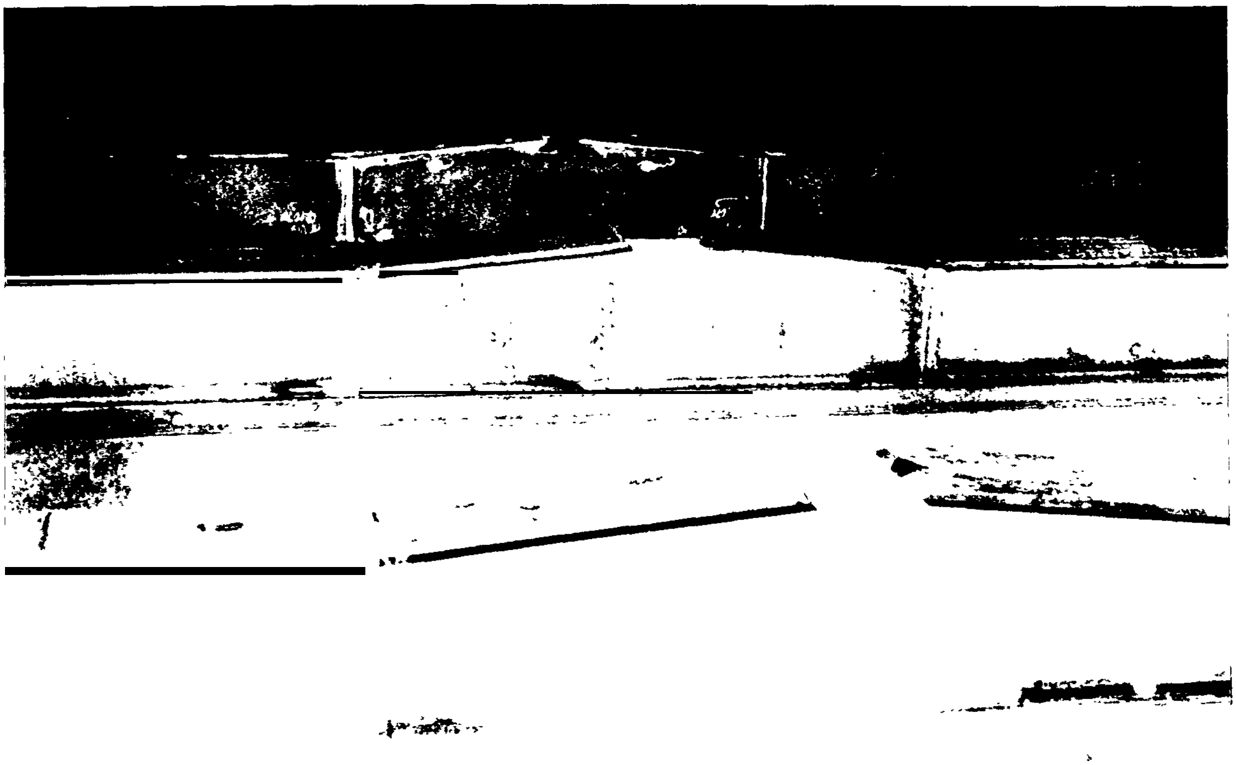

Figure 5 HSLA-1OO deck panel with stiffeners before transverse structure is attached

shop was between 18 & 27°C (65-80°F), so no applied preheating was required. Panels (usually consisting of three or four deck plates) were welded on the first side with twin wire SAW. After the first side was completed, the panels were turned over and the welds were backgouged. Root magnetic particle inspection (MT) was conducted, then the second side of the welds was completed with twin wire SAW. After the HSLA-100 deck panels were completed, they moved further up the panel line to have HSS or 0SS back-up structure attached (Figure 3). Much of the stiffener structure was welded with a dual head SAW gantry system. Figures 4 and 5 show ***a*** panel assembly after longitudinal stiffeners have been welded. Many of the deck assemblies also had transverse structure added, which involved considerable semiautomatic welding, such as GMAW or FCAW (Figure 6). Some deck panel assemblies were heavily stiffened, which increased the level of required restraint for fitting and welding (Figure 7). If weld cracking problems were to cccur, these more complex assemblies would most likely have shown indications. Once the welding and inspection was complete, units were transported to a platen area with heavy lift capability for "superlift" assembly.

As previously discussed, several different welding processes were used during the initial stages of construction. However, SAW was the primary process used for welding HSLA-1OO plate together. During the superlift assembly and ship assembly stages, overhead GMAW-P was used extensively to weld the bottom side of the deck welds. Table I shows typical processes, consumable, and welding positions used during 1991 and 1992 for joining HSLA-1OO. Table II lists the established preheat and interpass temperature limits for

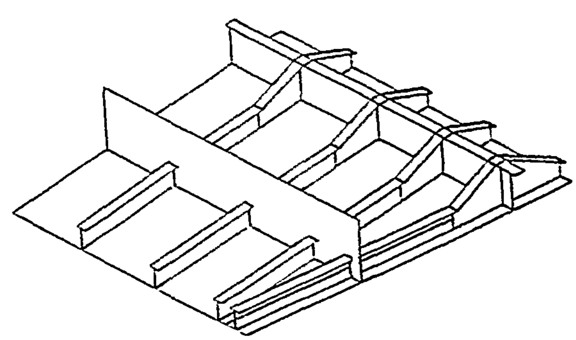

Figure ***6*** HSLA-1OO deck assembly design with Longitudinal and transverse backup structure

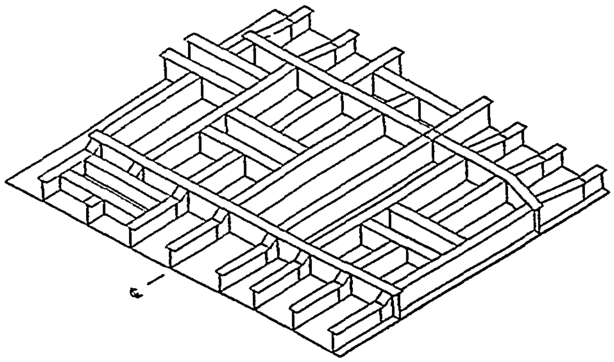

Figure 7 Heavily stiffened HSLA-1OO deck panel design

the processes. Heat input limits for the application of the processes are the same as those qualified for HY-100 welding.

Inspection Processes and Data Analysis

Visual Inspection (VT) was required for all welds during and after welding. In addition, 100% MT was required for all butt welds in HSM-100. MT inspection was usually performed within one to eightweeks after welding, with an average of about three weeks after welding.

Weld inspection data from each HSLA-100 unit assembly on CVN 74 was compared with data from the same unit on CVN 73, where HY-l was used. Periodic quality assurance reports were used to track inspection results for comparison of HSLA-1OO with HY-1OO welding.

Non Destructive Test Results

Initally, to support the implementation plan, 27 deck subassembly units were fabricated, welded, VT'd and MT'd in the shop. The total HSLA-1OO weight for these 27 units was 836 metric tons (759 long tons). This included 403 metric tons (366 long tons) of 22.2 mm (O. 875 in.) HSLA-100 plate and 433 metric tons (393 long tons) of 25.4 mm (1.0 in.) HSLA-1OO plate. A total of 423,000 mm (16,656 in.) of butt weld in the 22.2 mm (0.875 in.) HSLA-1OO plate was inspected with a total of 203 mm (8 in.) of repair weld being required in two locations. Neither repair area contained

Process	Electrode Type	Flux Type	Welding Position
SAW	MIL-100s-l	MIL-1OOS-1F	FLAT
GMAW	MIL-1OOS-1	NA	FLAT OR HORZ.
GMAW-P	MIL-1OOS-1	NA	ALL
SMAW	MIL-11018	NA	ALL

Table I Typical welding processes, filler materials and welding positions for HSLA-1OO

HSLA-1OO Thickness mm (in)	Minimum Preheat & Interpass Temperature: °C (°F) 1/		
	SMAW	GMAW/GMAW-P	SAW
≤25.4 (1.00)	15.6 (60)	15.6 (60)	15.6 (60)
>25.4 (1.00) To <31.7 (1.25)	51.7 (125)	51.7 (125)	51.7 (125)
31.7 (1.25) To 69.8 (2.75)	93.3 (200)	65.6 (150)	65.6 (150)
Over 69.8 (2.75)	93.3 (200)	93.3 (200)	93.3 (200)

1/ Maximum preheat and interpass temperature is 149°C (300°F)

Table II Established preheat and interpass temperature limits for welding HSLA-1OO to itself

any transverse cracks or hydrogen related defects. A total of 420 meters (16,524 in.) of butt weld in the 25.4mm (1.0 in.) HSLA-1OO plate was inspected with no repairs required. Records for the same HY-1OO units on CVN 73 were examined 813 mm (32 in.) of rejectable indications were recorded for 850,000 mm (33,468 in.) welded.

Since the initial implementation phase of this project, those same 27 deck units on CVN 74 were joined into larger subassemblies, and later were set into place on the ship, and welded and inspected. Total inspection for HSLA-100 shop and shipboard welding operations amounted to approximately 1,270,000 mm (50,000 in.) of weld, with 813 mm (32 in.) requiring weld repair (less than 1/10 of 1%). The defects in the later cases initially appeared as transverse cracks on the weld surface, but upon excavation were found to originate from lack of fusion and slag defects. These defects were caused by poor access to the lower side of the weld joints in way of stiffener crossovers.

Overall, the initial phase of the program was considered a complete success; this led to the next phase incorporating additional HSLA-1OO in the ship.

ADDITIONAL HSLA-1OO ON CVN 74

Since it was demonstrated that HSLA-1OO material could be satisfactorily welded with reduced preheat in a production environment, the shipyard began ordering additional HSLA-1OO steel (including thicknesses greater than one inch) for the substitution of HY-80 and HY-104 on CVN 74 and CVN 75. Since CVN 74 was already midway through construction, a special engineering/design effort was required to incorporate this additional HSLA-l material. The following step-by-step plan was used to identify and purchase all of the additional HSLA-1OO steel used on CVN 74:

1. A cut-off date for material required-in-yard was established for purchase orders. Orders scheduled to be placed after the established cut-off date became candidates for HSLA-1OO.

2. Purchase orders identified in Step (1) were reviewed to insure that HY-80 and HY-1OO material had not been received early or was not in the process of being rolled early. In this effort, the shipyard's purchasing department "Plate Track" computer program was used to identify in-process material.

3. All drawings that detailed the HY-80 and HY-1OO material that was to be ordered via the candidate purchase orders were reviewed.

4. Engineering personnel then determined if there were large enough areas of HY-80/100 on these drawings to make the substitution worthwhile. It was not beneficial to substitute HSLA-1OO if it was mixed with strakes of HY-80 or HY-1OO, since applied preheat is usually required when welding HSLA-1OO steel to HY steels.

5. Once steps (1) through (4) were accomplished, existing purchase orders were modified and new purchase orders were created for the HSLA-1OO that could be substituted. Detail drawings were then revised to reflect where the HSLA-1OO would be used.

Approximately 1270 metric tons (1250 long tons) of HSLA-1OO are being installed on CVN 74. Table III shows a breakdown of tonnage and thickness. The majority of tonnage clearly falls within the limits for reduced preheat: less than or equal to 25.4 mm (1.0 in.) thick. For those areas where the thickness is greater than 25.4 mm (1.0 in.), HY-1OO welding preheats are still being used. This need to preheat results from limitations of the welding consumables, not the base material. Less hydrogen sensitive consumables are under development to allow reduced preheat for welding thicker HSLA-1OO material.

THICKNESS mm (in)	TONNAGE metric (long)
15.9 (0.625)	-272 (-268)
22.2 (0.875)	-381 (-375)
25.4 (1.00)	-481 (-473)
>25.4 (>1.00)	-46 (-45)
MISC	-90 (-89)
TOTAL	-1270 (-1250)

Table III Use of HSLA-1OO on CVN 74

HSLA-1OO ADVANTAGES

There are many cost factors to consider when evaluating the use of HSLA-1OO steel in lieu of HY-100, such as equipment, equipment maintenance, set-up labor, energy, schedule impact, automation hindrance, delays (preheat/interpass), welder operator factor, and clean-up labor. Some of these factors, such as equipment and labor, have easily assignable costs. However, for other intangible benefit factors, such as enhanced automation and increased welder operator factor, it is difficult to determine the exact cost benefit.

For preheat cost saving considerations, most areas where aircraft carrier units are constructed are enclosed and ambient temperature is normally above 15.6°C (60°F). For HSLA-1OO with a thickness of 25.4 nun (1.0 in.) or less in these areas, application of welding preheat is normally no longer required. Heating equipment capital, maintenance, set-up labor, energy and clean-up labor costs, which could be assigned on a per ton or per length of weld basis, in this case would be no longer applicable. As the thickness increases the amount of heating equipment per given length of weld may increase as well. If, for example, heater bars are typically used, then it would be appropriate to determine the number of bars of a given size normally used per equivalent ton of HY-1OO structure to develop the associated cost savings.

The schedule impact of using HY-1OO is being evaluated. Delays can be incurred by the application and removal of heating equipment, and waiting for welds to reach proper preheat temperature, or to cool down to the proper interpass temperature. The total cost of facilities and other equipment used but not contributing to deposited weld may be difficult to determine so it would be appropriate to assign a percentage value for delay time cost savings. Also, automated process improvements and higher productivity may result from the elimination of preheat. However, if hard to quantify, productivity improvements could be estimated with a percentage value as well to arrive at a cost per ton savings figure. Together, these individual cost factors are a good baseline for estimating preheat cost savings.

Considering base material expense, initially the cost of HSLA-1OO steel plate was expected to be substantially higher than HY-1OO, due to higher alloy content. But shortly after the implementation program was under way, the lean chemistry grade of HSLA-1OO was certified for thicknesses of 25.4 mm (1.0 in.) and less. This lean chemistry formula led to reduced costs and, along with reduced preheat, increased the potential cost savings for the substitution. Also, the price of both lean and rich chemistry HSLA-1OO steel has been reduced since initial purchase. In January, 1990, the average cost difference of HSLA-1OO steel plate over HY-1OO plate was $142.50 per metric ton. In March, 1993, the average difference in cost was just $20.00 per metric ton.

The exact total cost difference in dollars per ton between HSLA-l00 and HY-1OO construction varies. It depends largely on the complexity of an assembly, and the extent of attachment welds no longer requiring preheat. Energy and labor costs are the two major factors. Rough order of magnitude savings estimates range anywhere from $500 to $3000 per metric ton before any applicable implementation costs are considered.

FURTHER APPLICATIONS

Once initial welding of HSLA-1OO with reduced preheat was satisfactorily proven on CVN 74, planning began immediately for widespread substitution of HSLA-1OO on CVN 75. As of March 1993, a total of about 15,420 metric tons (14,000 long tons) of HSLA-1OO is scheduled to be substituted on CVN 75. An even greater use of HSLA-100 is planned for CVN 76.

Welding procedure qualification tests with new lower diffusible hydrogen consumables are providing promising results. The primary objective is to increase the thickness at which 15.6°C (60°F) preheat can be used to produce satisfactory welds in a worst case environment under conditions of high restraint.

CONCLUSION

With reduced defense budgets and ever increasing pressure to cut costs, the use of HSLA-100 steel on Naval combatant ships is a significant step in the right direction.

Cooperation and thorough planning by the Navy, steel suppliers (Bethlehem Steel, Lukens Steel and United States Steel) and the shipbuilder have resulted in a successful implementation program of HSLA-1OO steel on CVN 74 with reduced welding preheat.

Some suppliers of welding consumables (ESAB/L-TEC and Lincoln Electric company) are currently concentrating on the development of new filler

materials that could lead to the welding of thicker HSLA-1OO steel with reduced preheat. Their ability to provide the very low diffusible hydrogen consumables needed for reduced preheat welding is the key element in taking full advantage of this new steel.

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